END OF YEAR REPORT

LONG WAVELENGTH SEMICONDUCTOR LASERS DEVELOPMENT FOR INFRARED HETERODYNE APPLICATIONS

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Introduction

This report will summarize the first year effort of a three year program aimed at developing molecular beam epitaxy (MBE) grown double heterostructure (DH) lasers operating in the 16-28 μm range for use in infrared heterodyne spectroscopy.

Assumptions and Guidelines regarding the methodology used in planing and conducting the research and development of MBE grown PbSnTe long wavelength lasers, were extracted from the existing MBE technology at Laser Photonics Analytics Division (LPAD) which is successfully used to produce high quality single mode PbTe/PbEuSeTe buried heterostructure lasers emitting in the 3-6 μm spectral range. Following the completion of fluxes vs. temperature, growth rate, lattice matching and doping calibrations the growth parameters for the production of $Pb_{0.78}Sn_{0.22}Te$ have been set. It was then found that the parameter set up is not producing diode lasers which meant that our assumption that the PbSnTe system behaves similarly to the PbEuSeTe system were wrong and a different approach was tested, this time producing PbSnTe diode lasers. Electrical and optical test results will be presented, analyzed and summarized followed by the suggested outline for a second year effort.

Growth of PbSnTe and PbSeTe substrate crystals

$Pb_{0.78}Sn_{0.22}Te$ and $Pb_{0.72}Sn_{0.28}Te$ single crystals were grown to be used for substrate wafers. These compositions are identical to the planed active layer compositions. In addition $PbSe_{0.087}Te_{0.913}$ and $PbSe_{0.087}Te_{0.913}$ single crystal were grown. The latter are identical in composition to the calculated cladding layers. Both the PbSnTe and the PbSeTe crystals were intentionally doped p-type with Tl to hole concentration of $2x10^{19}$ holes/cm^3. Detailed calculations can be found in the first quarterly report.

MBE growth parameters calibrations

MBE epitaxial growth occurs when molecular beams from the various effusion sources reach the surface of a heated substrate and the various molecules react to create a binary, ternary or quaternary crystalline mono-layer. Basically a combination of the ratio between the various fluxes and the sticking coefficients of the molecules at the specific substrate temperature determine the precise epitaxial layer composition. It is obvious therefore that the first step was to establish the connection between furnace temperature and the molecular flux of this source as measured by an ion beam. The next step was to establish the connection between the fluxes and growth rates. For example combining growth rates from the PbTe and $Pb_{0.7}Sn_{0.3}Te$ sources enables one to engineer any $Pb_{1-x}Sn_xTe$ composition in the range of $0.3 > x > 0$ providing that the sticking coefficient for each molecule is known. A similar situation exists for $PbSe_yTe_{1-y}$ which is the product of the PbTe and PbSe molecular beams. Detailed information about these calibration was given in the first and second quarterly technical reports.

Lattice matching

As part of the laser structure design PbSeTe epitaxial layers are grown to serve as cladding layers to the narrow band gap PbSnTe active layer. Lattice matching conditions between the PbSnTe ternary compound to the PbSeTe ternary compound can be calculated as demonstrated in the first quarterly technical report. Practically, the active PbSnTe layer is grown on top of a BaF_2 substrate followed by the calculated lattice matched PbSeTe. The top layer thickness is chosen to be about $1\mu m$ in order to enable penetration of the x-ray beam into the underlying PbSnTe layer. The precise growth parameters that fulfill the lattice matching requirement are determined empirically after analyzing the x-ray diffraction data. Detailed information and results of the lattice matching conditions for $Pb_{0.78}Sn_{0.22}Te$ and $Pb_{0.72}Sn_{0.28}Te$ active layers were presented in detail in the second quarterly technical report.

Doping studies

Bi and Tl are known to be efficient n and p-type dopants for PbEuSeTe compounds. Actually to increase the doping efficiency (incorporation) of Bi and Tl atoms into Pb salts Bi and Tl chalcogenides compounds are used as charges in the effusion sources. Bi_2Te_3 and Tl_2Te binaries were found to be most efficient dopants for MBE grown PbEuSeTe compounds. Based on the assumption that PbSeTe compositions used for cladding are Te rich and therefore will behave similarly to Te rich PbEuSeTe doping wise, we repeated the doping experiment carried out for the later compound. As found this approach was well justified as we have reported in detail in the second and third quarterly technical reports. The main difference between the PbEuSeTe system and the PbSnTe system is in the carrier concentration of the undoped Te rich active layer. While the measured hole concentrations of Te rich PbEuSeTe is about $1x10^{17}$ holes/cm^3 the hole concentration of Te rich $Pb_{0.78}Sn_{0.22}Te$ for instance is about $5x10^{17}$ holes/cm^3. This difference might require further consideration when optimizing PbSnTe laser performance (Doping profiles).

Fabrication of broad area lasers

Using the lattice matched structure and the calibrated doping data, we attempted to grow broad area DH PbSeTe/$Pb_{0.78}Sn_{0.22}Te$ lattice matched lasers with doping profiles similar to those used for the PbEuSeTe system. Unfortunately this attempt failed not only to emit light but also resulted in I-V characteristics that resembled more ohmic behavior rather than diode properties as reported in detail in the third quarterly technical report. Small adjustments to the doping profile for similar MBE runs with $Pb_{0.78}Sn_{0.22}Te$ and $Pb_{0.84}Sn_{0.16}Te$ (New composition with smaller Sn content) active layer were unsuccessful as well. The failed attempts resulted in a change of direction where laser structures with low Sn content PbSnTe active layer were prepared. In order to simplify and speed up the research these structure were not lattice matched and contain PbTe as a cladding layer. Doping profiles were also changed to contain higher dopant concentration in the cladding layers. This approach proved to be fruitful providing us with the first MBE grow PbSnTe lasers. Detailed test data will be presented in the next chapter.

Laser testing

Three nominal PbSnTe compositions were grown , packaged and tested. Active layer composition was calculated from the molecular source fluxes of the PbTe and the $Pb_{0.7}Sn_{0.3}Te$ effusion cells. Electrical testing, included I-V characteristics and I-L characteristics and was carried out at 12 K. The current-light output was measured using a Cu doped Ge detector and is given in arbitrary units. Optical test were carried out at 24 K (nominal-20 K measurement) , results are summarized in Table I and shown in figures 1-3.

TABLE - I

Run #	Laser #	Composit. at.% Sn	Rs (mΩ)	Emission (µm)	Tun. Rate MHz/mA	Ith (mA) (Electrical)	Figure #
251	9334.22	2.0	57	7.25	259	429	1
261	9347.17	3.0	89	7.65	144	308	2
243	9349.07	4.0	62	8.2	225.3	119	3

Summary and conclusions

We were able to produce broad area lasers with active region nominal compositions up to $Pb_{0.96}Sn_{0.04}Te$. However by substituting the emission wavelength into the band gap-composition empirical formula (see 1st quarterly technical report) we have found that the actual Sn content is twice the amount calculated from the beam flux ratios. This might suggest that the sticking coefficient of the PbSnTe molecules is twice what we assumed it will be.

Recommendation for future work

A. Continue MBE laser runs increasing Sn content in the active layer.

B. Repeat successful runs with lattice matched cladding layers.

C. Further optimize doping profiles.

D. Transfer to striped active layers.

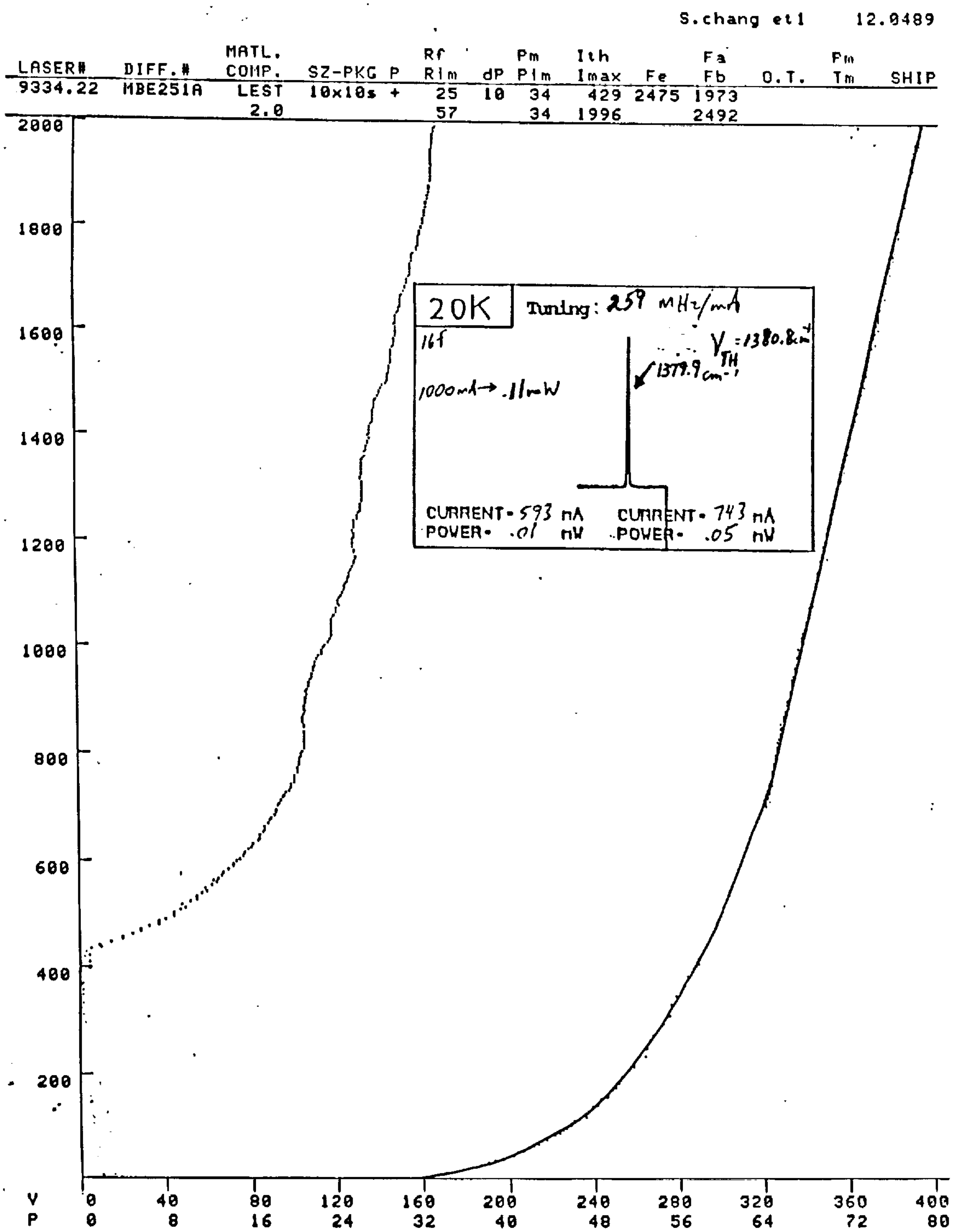

Figure 1. - Standard electrical test including I-V and I-L characteristics for diode 9334.22 with a calculated $Pb_{0.98}Sn_{0.02}Te$ active layer. The insert represents the standard optical test data done at 24 K (Nominal 20K).

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LASER#	DIFF.#	MATL. COMP.	SZ-PKG	P	Rf Rim	dP	Pm Pim	Ith Imax	Fe	Fa Fb	O.T.	Pm Tm	SHIP
9347.17	MBE261A	PbSnTe 3.0	10x10S	+	93 89	10	29 29	308 1284	1368	2321 ~~3610~~			

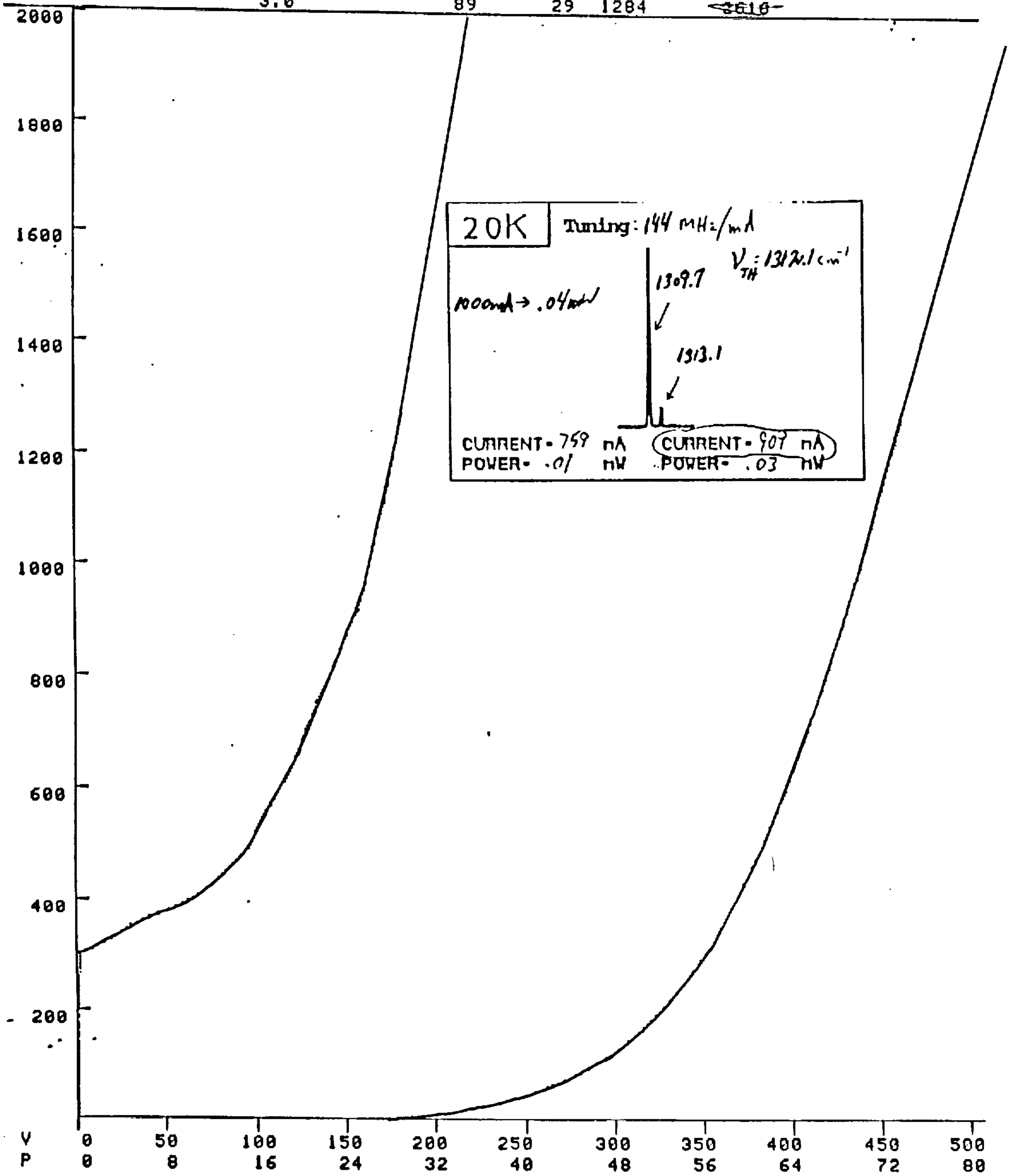

Figure 2. - Standard electrical test including I-V and I-L characteristics for diode 9347.17 with a calculated $Pb_{0.97}Sn_{0.03}Te$ active layer. The insert represents the standard optical test data done at 24 K (Nominal 20K).

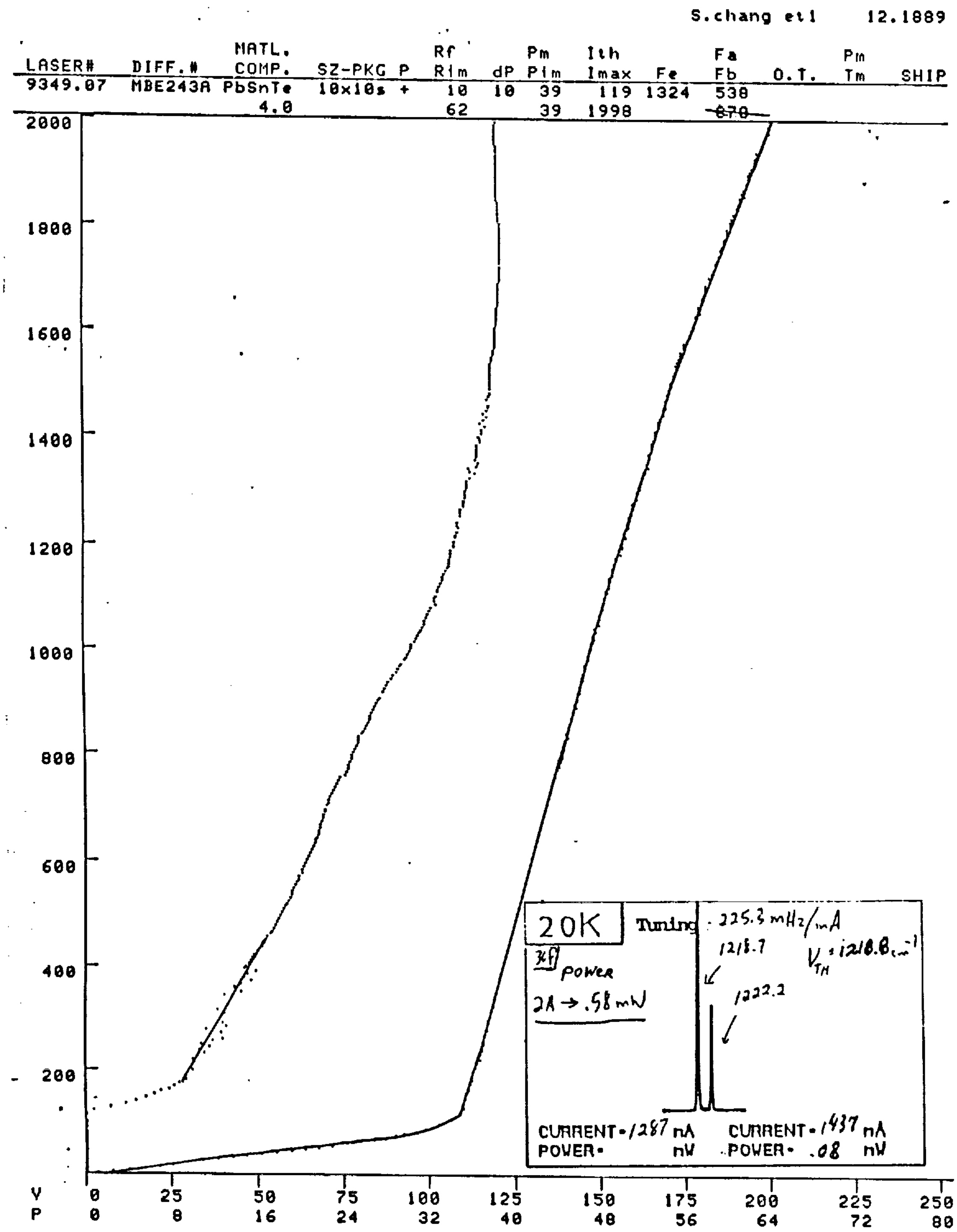

Figure 3. - Standard electrical test including I-V and I-L characteristics for diode 9349.07 with a calculated $Pb_{0.96}Sn_{0.04}Te$ active layer. The insert represents the standard optical test data done at 24 K (Nominal 20K).

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16. Abstract

PbSnTe single crystals have been grown in a new 3 zone furnace. MBE growth parameters have been established including, beam flux vs. temperature, growth rates and dopant vs. PbTe flux ratioes for the various effusion sources involved. Lattice matching studies have been conducted and doping studies have been completed. Broad area $Pb_{1-x}Sn_xTe$ double heterostructure lasers have been fabricated with active layer compositions up to x=0.04 at.% Sn in the active layers. Electrical and optical test data is presented.

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